AMERICAN JOURNAL OF PHYSICAL ANTHROPOLOGY 107:315–330 (1998)

An Alternative Method for Assessing Early Mortality in Contemporary Populations

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KEY WORDS infant mortality; development; methods; statistics

ABSTRACT Biological anthropologists are interested in a population's early mortality rates for a variety of reasons. Early mortality (infant or juvenile) is of obvious importance to those interested in demography, but early mortality statistics are useful for life history analysis, paleodemography, and human adaptability studies, among others. In general, the form of mortality statistics is derived from demography, where chronological age is the gold standard for statistical calculation and comparison. However, there are numerous problems associated with the collection, analysis, and interpretation of early mortality statistics based on age, particularly for anthropological research, which is often conducted in small or non-calendrical-age numerate populations. The infant mortality rate (IMR), for example, is notoriously difficult to determine in populations where accurate accounting of age is not routine, and yet it is widely used in demography, public health, medicine, and social science research. Here we offer an alternative to age-based early mortality statistics that makes use of human biologists' interest in, and skill at, assessing human growth and development. Our proposal is to use developmental stages of juveniles instead of relying exclusively on age as the basis for mortality statistics. Death or survival according to a developmental stage (such as crawling or weaning) may provide more accurate data that are also more closely related to the cause of death. Developmental stages have the added advantage of putting infants and children back at the center of the discussion of early mortality by focusing on their activities in relation to their environment. A case study from the Turkana population of Kenya illustrates the use of developmental stages in describing early mortality. Am J Phys Anthropol 107:315–330, 1998. © 1998 Wiley-Liss, Inc.

Biological anthropologists have long been interested in demographic rates, for a variety of reasons. Vital rates reveal the structure and growth rates of contemporary and past populations, and thus are useful to the study of human variation and evolution. Since fertility and mortality are so fundamental to natural selection, evolutionary studies hinge to varying degrees on assessment of the magnitude and timing of these events. On a finer scale, fertility and mortality schedules are integral parts of life history analysis, reproductive ecology, and studies of human adaptation and adaptability. However, standardized demographic statistics may be inappropriate for use in the kinds of small-scale studies that biological anthropologists often carry out, in part be-

Grant sponsor: NSF; Grant numbers: BNS-8912768, BNS-8718477, DBS-9207837; Grant sponsors: the Population Council, the Kenya Medical Research Institute, Wenner-Gren Foundation.

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Received 24 March 1998; accepted 9 July 1998.

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cause they require the very large datasets typically used in demography (e.g., national-level censuses and surveys). There have been several attempts to refine demographic methods and analysis for anthropological populations (Gage, 1985; Hill and Hurtado, 1996; Howell, 1979; Wood, 1994), and here we argue that standard statistics on early mortality, particularly the infant mortality rate (death in the first year of life; IMR), are inadequate for many types of anthropological research, and we suggest an alternative model for collecting and analyzing data on early death. We are especially concerned with the use of the IMR in research on contemporary human populations. (In medical anthropology there has been a call for anthropological involvement in the construction and interpretation of health statistics. As Nichter and Kendall have argued, "in an international health setting in which 'body counts' and extrapolated statistics carry immense weight in health and development planning, anthropologists have not been vocal enough in questioning the meaning of health statistics and helping to construct more appropriate indicators of ill health" [1991:196].)

Statistics on early (infant and child) mortality are of special interest to those studying human adaptation and adaptability. Baker and Dutt (1972), Mazess (1975), and, later, Little (1989), among others, have all identified infant and child mortality rates as measures of adaptability, that is, as markers of how human populations are able to respond to the challenges of their local environment. As the domains of reproductive ecology and life history inquiry have come of age in biological anthropology, the need for information on early mortality has further increased. Life history studies have routinely identified local juvenile mortality rates as important predictors of life history parameters among mammals (Promislow and Harvey, 1990; Stearns, 1992). Collection of reproductive histories and calculation of infant and child mortality rates has become routine for anthropologists working in these interrelated areas. Thus, there is a need for data that are accurate and locally meaningful, but that can also be used in cross-population comparisons. The IMR is difficult to use in these contexts for several reasons, and we suggest a new model that uses standardized developmental stages as an alternative to chronological age in the collection of data and calculation of statistics on early death. Developmental stages tend to be related to the actual cause of death, thus also potentially clarifying the interpretation of death statistics. Attention to the developmental pattern of death, as opposed to simply the magnitude of death rates at standardized ages, reveals a more meaningful picture of mortality, and can illustrate the interactivity of the individual's biology and environment in contributing to death or survival as development unfolds.

We begin with a discussion of some problems with the calculation of the IMR statistic, appropriate interpretation of infant mortality statistics, and collection of infant mortality data. IMR statistics are most frequently used in public health and demography research, and the assumptions and conclusions of researchers in those fields may be quite different from those of biological anthropologists. Following this, we elaborate an alternative model for early mortality, one that may be more appropriate for the kinds of research that biological anthropologists often conduct, but which may also have broader applications. The model is illustrated with some preliminary data on the pattern of early deaths by developmental stage derived from the Turkana population of Kenya.

IMR — PROBLEMS OF CALCULATION AND INTERPRETATION

At first glance, the IMR appears to be a simple descriptive statistic, but there are substantive problems with both the collection of accurate data to generate the statistic and its appropriate interpretation. In standard form, the IMR is calculated as the number of deaths of infants less than one year of age during one calendar year, divided by the number of live births during that same year. This ratio is usually expressed as deaths per 1,000 live births and is indexed to the year. Despite its name, the IMR is not a true rate; the population represented in the numerator is not derived exclusively from the population listed in the denominator.

The IMR for any given year is sensitive to, among other things, seasonal variation in the timing of birth and death, which has been documented in many places at the local and national level (Leslie and Fry, 1989; Seiver, 1985; Urdry and Morris, 1967). If, for example, births are clustered prior to the season of greatest risk of death the IMR will be inflated for that year relative to a situation where births are evenly spread throughout the year. The IMR will be higher, even while the underlying risk of death remains constant. Further, changes in the IMR over several years may be due to changing annual birth rates. These effects may be minor at the national level, but important at the local level, where small and fluctuating numbers of births can disproportionately affect the IMR. This problem with the standard construction of the IMR can be overcome by using a cohort rate instead of a period rate (the yearly tally of deaths relative to the yearly tally of births). That is, data on infant deaths derived from reproductive histories or prospective studies can provide rates where the numerator is derived from the denominator, thereby obviating the above problem.

An interpretive problem with the IMR is its appropriate referent. In public health reports, the IMR is most often seen as an index of the quality of the social environment. The IMR is a key component of the physical quality of life index (PQLI), and is generally considered a "quick and dirty" index of a population's standard of living (Morris, 1979). This usage of the IMR has a long history; since at least 1910, IMRs have been touted as "the most sensitive index we possess of social welfare and sanitary administration" (Newsholme 1910, quoted in Yankauer 1990). This is a limited interpretation, and one that might not readily come to mind to biological anthropologists. More broadly, infant mortality may be the outcome of *environmental* (natural and/or social) conditions, *genetic* conditions common in a given population, or it may derive from the interaction of genes and environment, as expressed in *ontogenetic* conditions. Therefore, there may be high or low infant mortality *areas*, or high or low infant mortality *populations*, or some combination thereof. In order to specify the appropriate referent we need to have a more complete appreciation of how the environment (both social and natural), biology (as a population level characteristic), and behavior (as an individual and population level characteristic) interact to produce different levels of infant mortality. This demands analytical frameworks such as proximate determinants models (Chen, 1983; Millard, 1994; Mosley and Chen, 1984) that can adequately detail these interrelationships, as well as different kinds of statistics.

The contribution of intrinsic population characteristics to infant mortality is illustrated in the following example. In the United States there are striking differences in infant mortality rates between Euro-Americans and African-Americans, which have been the subject of much investigation. Overall, infant mortality has declined in the two populations over the past decade as a function of social investments in health, but the ratio of black infant mortality to white infant mortality rates has not declined (Wise and Pursley, 1992; Yankauer, 1990). There are well-described differences in the average birthweight of newborns in both populations — blacks on average have significantly smaller newborns, which contributes to their higher level of infant mortality. Whether black–white differences in birthweight are uniquely due to genetic factors is a matter of considerable debate (Foster et al., 1993; Mangold and Powell-Griner, 1991), but this effect remains even when socioeconomic factors and prenatal care have been controlled for (Collins et al., 1997; Schoendorf et al., 1992). For example, infant mortality attributable to low birthweight was found to be substantially higher in college-educated blacks than in whites of similar education (Schoendorf et al., 1992). This suggests that there may be heritable population differences in underlying risk that result in variation in infant mortality statistics between populations living in similar social and physical environments.

Other biological factors contribute to variation in early mortality across populations. In general, females have a biologically based survival advantage in infancy that is evident at any level of infant mortality (Ruzicka and Kane, 1990). As the infant ages,

this advantage may disappear or be exaggerated as a function of cultural preferences for males, or behavioral differences between males and females (McKee, 1984; Miller, 1987; Obermeyer and Cardenas, 1997; Super, 1984). In the absence of overt preferences, females retain a survival advantage (Ruzicka and Kane, 1990). So there is a biological risk factor (i.e., being male) that is constant, and an environmental component (evident at the household and community level) that is highly variable in its effects on infant mortality.

The environmental, genetic, and ontogenetic inputs to infant mortality each act in different ways, and at different times during the first year of life. Thus, the IMR is a composite rate, made up of several component rates, each with its own relative sensitivity to environmental, genetic, and ontogenetic influences (Wise and Pursley, 1992). One refinement that adds interpretive value to early death rates is a closer examination of the *pattern* of mortality in the first year of life. The pattern of death among infants is significant because the developmental stages the infant goes through predispose it to different risks of death as it ages. Two populations may have the same *level* of IMR, but a very different age pattern, indicating substantial variation in underlying risk factors. A breakdown of the first year into risk periods provides a much more useful and descriptive picture of infant health, and helps specify the relationship between early mortality and its correlates.

In general, in contexts of high infant mortality mortality risk increases as the infant moves through the first year of life. Mortality is often high immediately following birth, dips, then increases throughout the months of the first year. In contrast, in low mortality contexts the risk of death is highest in the first month (neonatal mortality) and declines over the next eleven months. Neonatal deaths comprise a much higher percentage of infant deaths in low-mortality contexts than in high-mortality contexts. Demographers make a distinction between infant deaths deriving from *endogenous* causes (prematurity, congenital defects, or birth trauma) which occur soon after birth and which are considered to be relatively unavoidable, and those that result from *exogenous*, or environmental causes, which disproportionately occur later in the first year of life, and which may be more amenable to intervention (Pressat, 1972). Thus, the age pattern of mortality is useful in understanding the relative contributions of biology and environment to infant mortality. In a study from Nigeria, biological characteristics (congenital problems, birthweight, birth order, sex, etc.) were found to be significant predictors of mortality at one month but not in the postneonatal period (Ahonsi, 1995). Household hygiene was found to be significantly associated with postneonatal mortality but not neonatal mortality. In a comparison of survey data from 17 developing countries, researchers found that maternal education had no effect on the neonatal mortality rate, but significant effects on the postneonatal mortality rate (Bicego and Boerma, 1993). The fact that the determinants of mortality change over the course of the first year of life indicates that the level of infant mortality is a gloss for a wide array of risk factors that do not affect infants of all ages similarly.

The age pattern of early death and its interpretation: An example

A case study from Ladakh, a mountainous district in the northernmost part of India, illustrates the utility of using the age pattern of early death, particularly in studies of human adaptability, for understanding the effect of various environmental stressors and genes on early survival. Ladakh is an extremely arid mountainous region of India, situated at the western end of the Tibetan plateau. Significant ecological features of this area include its dramatic seasonal variation in temperature, extreme aridity, and hypoxia (low oxygen pressure) due to its high altitude (3,000–4,000 m). An anthropological research project carried out in Ladakh in 1989–1991 included a retrospective study of infant mortality based on the reproductive histories of almost 300 multiparous women who had a live birth in the hospital in 1990, and a prospective study of 168 newborns who were assessed anthropometrically at birth and followed for up to one year to determine their survival and health sta-

tus (Wiley, 1992, 1994a,b). Analysis of the reproductive histories yielded a cohort infant mortality rate of 182/1,000 (Wiley, 1994a). Respiratory complications were by far the most frequently recorded cause of infant death.

Although the level of infant mortality is perhaps unremarkable for this developing-country context, the timing of infant death in Ladakh is distinctive; 79% of the infants who died did so within the first month of life. After the first month the mortality rate dropped dramatically — the postneonatal IMR was 38/1,000 (Wiley, 1994a). The most important factor contributing to this high neonatal mortality was the high frequency of low birthweights. The mean (and median) weight of newborns in the prospective study was 2,764 grams (Wiley, 1994b), and 27% weighed less than 2,500 grams, the WHO classification of newborns at risk (WHO, 1977). On average, infants who died weighed 400 grams less than those who survived, and hazard analysis showed that birthweight was a significant negative predictor of death in the first month, but not after three months (Wiley, 1994a). Studies have consistently demonstrated that birthweight is a strong predictor of neonatal mortality, and to a lesser extent postneonatal mortality, across populations and environments (McCormick, 1985). Since neonatal mortality makes up the vast majority of infant deaths in Ladakh, the factors that influence the high frequency of low birthweights are exerting a strong influence on the pattern of infant mortality. And, because the infant is exposed to the highest risk in the first month, there are relatively few opportunities to experience other environmentally based threats during this short period of time.

This pattern of low average birthweight has been found in high-altitude regions of the New World (Beall, 1981; Conlisk, 1987; Haas, 1980; Haas et al., 1977, 1980; Lichty et al., 1957; McClung, 1969; Yip, 1987), and is most likely due to exacerbated oxygen stress in utero, due to the hypoxic external environment. Average birthweight in Ladakh is much lower than that found in the Andean studies, and neonatal mortality is much higher (Mazess, 1965). Populations with longer antiquity at high altitude are characterized by higher average birthweights, and presumably lower neonatal mortality rates (Haas, 1980; Moore, 1990). This suggests a role for population genetic factors shaping mortality risk in the context of the particular set of ecological conditions of high altitude. Ladakhis appear to be of relatively recent origin in this high-altitude environment, and are probably a more genetically heterogeneous population compared to the indigenous populations of the Andes (Rabgias, 1988; Rizvi, 1983). Thus, the combination of maternal and offspring genes (forged in this case from multiple origins and not specifically adapted to hypoxia), ontogeny (genes acting in the context of gestation in a hypoxic natural environment), and the environment (primarily characterized here by hypoxia) contributes to the unique age pattern of early mortality in Ladakh.

In this case, attention to the age pattern of infant mortality points to the underlying causes of early death. Simply focusing on the high level of infant mortality would obfuscate the true picture of infants at risk. There is a very high rate of neonatal mortality but, after the first month, children appear to be relatively healthy and do not suffer from the traditional exogenous causes of mortality (infectious diseases and malnutrition) that so often characterize the first year of life for infants in the developing world and that affect Andean infants (Mazess, 1965). Interestingly, the unusual Ladakhi age pattern of infant mortality is not unlike that found in industrialized countries, where the proportion of infant mortality due to neonatal mortality is very high, although certainly the magnitude differentiates the specific causes of infant mortality in Ladakh from those in industrialized countries. This attention to pattern indicates the importance of genetic conditions, which in turn are related to ecological conditions and biohistorical factors, as key determinants of infant mortality.

AN ALTERNATIVE TO TRADITIONAL INFANT MORTALITY STATISTICS

Dividing up the first year provides a more informative look at early death, but requires very accurate age data. However, probably the most fundamental problem for the collec-

tion of infant mortality statistics is the accurate assessment of chronological age and/or underenumeration of deaths or births. Indeed, anyone who has attempted to collect infant mortality data need not be reminded of the numerous difficulties associated with this task. For anthropologists working with populations who do not track chronological age, or who do not track it on the same calendrical scale that Western populations routinely do, inaccurate age assessment of infants and children is pervasive, except in long-term prospective studies where birth dates are known.

Although researchers may find the tabulating of deaths for the first year of life to be an intuitively reasonable endeavor, it is worth noting that one year has no a priori cross-cultural or biological meaning in assessing mortality risk. The length of time from birth to one year or the attainment of any specific age acts as a standard unit for analysis and comparison, but does not necessarily conform to a biological or social phase of child development that has meaningful implications for mortality risk. Using one year to denote the life stage of infancy and as the cut-off age for describing early mortality is essentially an arbitrary choice, an artifact of the historical development of modern demography and a Western preoccupation with chronological age. As the cultural anthropologist Meyer Fortes noted:

> What must be emphasized is that stages of maturation over the individual life cycle are not determined by or coterminous with chronological age. Age in the latter sense is established by a cultural apparatus, a dating system that is independent of and neutral in regard to both the biological substructure and the social incorporation of maturational stages. . . . Western-trained anthropologists often project interpretations of chronological age on maturational field data, partly out of habit but mainly to relate their observations to the models of the life cycle that guide members of Western societies in the conduct of their lives (1984:101).

Changes in behavior toward children that may affect the risk of mortality can correlate with chronological age (e.g., weaning at the first birthday) in some cultures, but we would only expect this association if chronological age is being accurately tracked by caregivers. Given that this is not generally the case and that accurate age information is often difficult to obtain, and that at very young ages small errors in age reporting can yield dramatic differences in reported mortality rates, there is a need to explore other ways of tabulating early deaths that would be useful in describing local situations and, potentially, in cross-population comparisons. Furthermore, reliance on data collected by national institutions or non-governmental organizations (NGOs) may be problematic due to variations in the quality of their demographic event recording, in particular their classification of live-births-that-die-immediately-postpartum (infant mortality) as opposed to stillbirths (late fetal mortality), and the availability of vital rates for local areas. Each of these can have important impacts on the level of reported infant mortality.

Age misreporting

The problem of age misreporting for infants and children (particularly age-heaping at 1 year) has been addressed by workers at the Demographic Health Survey, who advocated an alternative way of describing early deaths by breaking up the first two years of life into three components: 0–1 month, 1–6 months, 7–23 months (Boerma and Bicego, 1991). In this way, mortality exclusive to the first year of life has given way to a focus on the latter age group, or "toddler mortality." While toddler mortality may more adequately reflect the pattern of deaths in many developing countries, this breakdown still requires relatively accurate age data by month. Moreover, the meaning of the threefold age breakdown is ambiguous and this system collapses potentially important age variation within the toddler period.

Other methods to deal with age misreporting (or non-age numeracy) by anthropologists have included using local historical events that can be accurately tied to a calendrical date (Little and Leslie, 1990), kinship terms that track relative age in combination with stable population theory (Howell, 1979), informant ranking of ages and informant estimates of absolute age differences (Hill and Hurtado, 1996), or some combination thereof. Methods specifically targeted to the problem of age misreporting of children have focused on finding biological developmental markers that can be easily identified by field workers, are reasonably

accurately correlated with chronological age, and are unaffected by environmental influences, such that they can be used as independent standards of comparison. Townsend and Hammel (1990) advocated using the pattern of tooth eruption as a proxy for calendrical age, a method that has been widely used in paleodemography and forensics. They based their method on the observation that the development of dentition is relatively independent of environmental influences, and that the orderly eruption of deciduous teeth can be fairly accurately correlated with age. However, this method excludes consideration of younger infants (<6 months), who usually do not yet show any tooth eruption, and ages children more precisely during phases of rapid dental development. The eruption of permanent teeth can only be used to estimate age for older children.

Human biologists have often used skeletal age as a developmental marker, although it is harder to assess in the field than dental development. However, as with other markers of growth and development, concern has focused on documenting variation in the chronological age that children reach a certain developmental stage as a problem of human variation and adaptability, rather than with using these stages as proxies for chronological age (Beall, 1984). The rate of skeletal maturation has been shown to be affected by environmental phenomena such as malnutrition, and hence cannot act as an independent standard of age (Eveleth and Tanner, 1990). It appears to be especially difficult to assess the skeletal age of infants (Eveleth and Tanner, 1990).

Using developmental stages as an alternative to age-based mortality statistics

What happens, though, if the assumption of the need for an external and independent standard of time is relaxed? That is, time (age) functions as the standard of comparison between populations precisely because it progresses at exactly the same rate for everyone, and thus events (e.g., death) by age can be meaningfully compared. However, the fact of the matter is that if calendrical age is tracked inaccurately or differently across populations, then age is not functioning as such a standard. One suggestion is to set aside calendrical age or any proxy thereof in favor of developmental markers, with the explicit understanding that their timing is likely to be highly variable across populations. Instead of the survival status at a given *age* being the outcome of interest in mortality analyses, survival status at a given developmental *stage* could be used. Useful stages would have to be those that are readily assessable among living children, and that could be easily recalled for dead children. Broadly defined stages such as crawling, walking, and weaning are the most obvious stages that come to mind for early mortality, but finer gradations may be possible.

It could be argued that for infants and children specifically, mortality is a function of age mainly insofar as age is correlated with development. Time does exert an independent, weak influence on mortality — every day there is a risk of dying, hence the longer you live, the greater the accumulated risk of death you have faced, but the probability of death is largely dependent on your risk factors. For the young, risk factors are likely to be strongly contingent on developmental stage. The age at which developmental stages are reached need not be the relevant or important point of comparison but rather reflects a derived or supplemental concern. Certain developmental stages are likely to signal discrete changes in risk of morbidity and mortality independent of, or potentially interacting with, chronological age. Development implies attainment of a level of competence in a physiological system (e.g., motor, linguistic, digestive, respiratory, etc.), and competence may either reduce or increase the risk of mortality. As an infant's ability to interact more intimately with the world around it increases, generally it becomes more vulnerable to environmental risks, until it reaches further stages of maturity. There are several reasons to believe that this method may hold some promise as an alternative way of standardizing descriptions and comparisons of early death. It does not overcome the additional problem of underreporting of dead infants, but it does

provide an alternative way of dealing with the problem of age misreporting.

The importance of developmental as opposed to chronological age is illustrated by the relationship between premature birth and mortality. It is well known that premature newborns have a much higher risk of mortality than do full-term infants even when they have the same birthweight (McCormick, 1985), but also that modes of estimating gestational age when the dating of pregnancy is not possible are notoriously inaccurate (Caulfield, 1991). Gestational age is often estimated from developmental indices of the newborn (Dubowitz et al., 1970), and then the estimated gestational age (EGA) is used to predict mortality. This is a cumbersome process and fraught with the potential for errors in age estimation. We suggest that these maturational indices could be used to predict mortality *directly*, without being converted to gestational age estimates, which would avoid the errors incurred in the estimation process. Categorizations of maturity (based on standard indices of growth and development) or simple distinctions between prematurity and full-term could be used instead of EGAs (more likely the latter, as the Dubowitz examination is fairly complicated and difficult for fieldworkers (Pike, 1996)). Developmental indices have the further advantage of illustrating the sources of mortality risk better than gestational age (e.g., underdevelopment of the respiratory system associated with mortality). It is also important to note that in conventional analyses, chronological age is used to compute infant mortality, and all newborns are assumed to be the same age at birth (i.e., 0), which obscures the contribution of relative maturity to mortality risk.

The developmental stage of crawling appears to be important with respect to changing morbidity risk (and hence mortality risk) for infants. Zeitlin et al. (1995) found that diarrheal disease among Bangladeshi infants was strongly correlated with the age at which they began to crawl. Crawling about the household compound increased contact with an environment contaminated by fecal matter and other detritus. In this case, it might have been just as enlightening to leave out age and report morbidity rates by the attainment of the developmental stage of crawling. Other motor stages such as walking might also be of use in describing the "developmental age" of an infant, and would have the additional advantage of describing a behavioral characteristic of a child that is likely to be meaningfully linked to mortality risk. We might expect, for example, that walking would be a less risky stage than crawling with respect to death from diarrheal disease, but would be a more risky stage for deaths from accidents. LeVine (1977) found that the Gusii of Kenya and several other African societies recognized walking as a risk factor for their children being burned by cooking fires and hospital records confirm this association.

Weaning is also an appropriate stage to use when investigating early mortality. Although weaning is not as discrete as biological markers such as crawling or walking (which themselves may not always be entirely discrete) and may be less tied to biological maturation, it is clearly an important biobehavioral developmental stage for children. In countries with relatively high rates of early mortality it has been observed routinely that weaning is associated with an increased risk of morbidity and mortality (mainly from diarrheal disease) across a wide range of ages (Briend et al., 1988; Molbak et al., 1994; Taylor and Greenough, 1989; Winikoff, 1988). In Guinea-Bissau, Molbak et al. (1994) found that weaned children age 12–25 months had 2.6 times the risk of mortality of breastfed children, and the higher rate of mortality was independent of age at weaning, again suggesting that it was weaning itself, not the age at which it occurred, that was important in predicting mortality. A similar finding has been reported from Bangladesh (Briend et al., 1988). In the Bangladesh study described previously (Zeitlin et al., 1995), the second peak of risk for diarrheal disease corresponded to the age at which mothers introduced significant quantities of supplemental foods. Again, the age clustering itself is not important in the sense that it does not indicate significant information about the cause of death. The developmental stage of

being weaned, on the other hand, is meaningfully related to mortality.

Potential problems with the developmental stage method

Some might argue that shifting from chronological age to developmental stage simply exchanges one problem for other, perhaps thornier, problems. This method is not intended to replace age as a universal standard for comparison, but in the absence of accurate age data it may provide a viable alternative, one that has the added advantage of being more descriptive of mortality risk than chronological age. A standardized taxonomy of developmental stages could be established that form the basis of a life table (truncated to stages of child maturation). The life table could derive from hazard analysis or ordered logistic regression using a series of suspected risk factors as covariates. It seems intuitively simpler to think of an infant being alive or dead at some developmental stage (e.g., crawling) as a function of a risk factor (e.g., unhygienic living conditions), rather than the stage *and* a series of risk factors acting as independent variables for predicting death at a particular age. If age data were available and accurate, it would be of interest to investigate whether age can act as an *independent* variable on survival probabilities at a given stage. It may turn out that age has important interactive effects in this way, a topic which has not heretofore been examined closely.

An additional potential problem concerns the closure of the last developmental interval. If, for example, weaning is the last developmental stage described, deaths after weaning could potentially span a large number of years. Puberty is one potential way to close the developmental stages, but it occurs around 10 years after weaning and is less marked for boys than for girls. Many cultures mark the attainment of "child maturity" as a stage in which children can begin to help with household tasks such as child care or animal tending (Weisner, 1996). The Turkana of Kenya (see below) recognize the stage of being a "big child," which is associated with these behavioral changes. Bogin (1997) has argued that the general lifestage of "childhood" conforms to this age interval (postweaning, premature).

At the same time, there is undoubtedly a need for finer-grained developmental markers in the early infancy period, before crawling or walking. At present, it is not clear what these would be, as early developmental markers such as following objects with eyes, sitting up, grasping objects, etc., are more subtle markers, and are more subject to interobserver variation (Lowrey, 1986; Sinclair, 1989). Appropriate developmental markers need to be both rapidly and accurately assessable by researchers, easily recalled by informants for deceased children, and should be meaningfully tied to changes in mortality risk.

Collecting accurate data on developmental stage

With respect to the accuracy of this approach and issues of data collection, it would seem that asking about developmental stage specifies a visible biological or behavioral referent as opposed to the abstract and invisible concept of chronological age. When eliciting reproductive histories or doing household censusing, interviewers could ask about the developmental stages of each child, living or dead. Questions such as "Is this child crawling/walking yet?" "Had this child been walking/crawling/weaned at some point before it died?" Instead of asking what age the child is or was when it died, which, again, is an abstraction, descriptors of the child's activities and characteristics should elicit more accurate information. Upon field testing, refinements of actual questions would most likely emerge and such questions could easily be part of a survey instrument or verbal autopsy inquiry. Although we assume that these developmental stages are universally recognized, and will be accurately reported, it is possible that informants attach significance to these events in ways that make them more likely to say, for example, that a child was walking or weaned when in actuality it was not. In this case, as in all cross-cultural surveys, close attention to the ethnographic context of development is essential in order to collect accurate data. There may be analogous indigenous ("-emic") categories of development that corre-

spond to assessable biological or behavioral development.

There is a wide range of cultural and environmental variability in the extent to which the attainment of developmental stages is hastened or discouraged by caretakers, or accelerated or retarded by environmental factors. However, the relative speed with which an infant reaches a particular stage is not necessarily important with regard to the relationship between reaching that stage and the risk of mortality. This was borne out in the previously cited reports on mortality and weaning that concluded that weaning itself and not the age at which it occurred was the important risk factor (Briend et al., 1988; Molbak et al., 1994). A related question concerns how illness, itself a risk factor for mortality, influences the attainment of a developmental stage and thereby confounds the relationship between stage and mortality. For example, an ill child may walk later than a healthy one, or an ill child may be weaned earlier or later than a healthy one. In standard analyses using death at age x as the dependent variable, weaning and illness become the two covariates, and they are highly correlated. Using death before or after weaning as dependent variables reduces illness to a single covariate. This analysis can show whether illness itself or the developmental stage during which it occurs is of crucial importance in determining mortality — that is, is it being weaned and sick rather than being sick that causes a child to die? This method avoids the problem of the covariation between developmental stage and illness posed in the traditional analysis by age and the compounding problem of age inaccuracies. If available, duration of the developmental stage would be an additional piece of useful information for sorting out the consequences of the behaviors that bring about attainment of a stage. Briend et al. (1988) found that Bangladeshi children who experienced an episode of bloody diarrhea were more likely to be weaned within one month than were healthy children. The observed higher mortality among weaned children might, therefore, be due to their experience of illness, not weaning per se. To test the possibility of a spurious association between weaning and mortality, the duration of weaning was analyzed as a predictor of prevalence of bloody diarrhea and risk of death. The prevalence of diarrhea significantly increased with the duration of weaning, but there was no excess disease or mortality from diarrhea among recently weaned children.

The question posed here is to what extent mortality can be described by stage instead of age and how mortality risk is related to stage across environments. With developmental stage as a standard we can then see more clearly the effects of differing environments on mortality using a biobehavioral standard that signals a potential change in risk for all children. Developmental stages of children are likely to incur different risks, depending on the environment in which they are expressed. Crawling and walking, for example, are not likely to be associated with dramatic increases in mortality from diarrheal disease in hygienic environments, but they continue to be associated with mortality from accidents and injury. The conversion of an injury to mortality is largely a function of the availability of medical care, and varies across environments. Investigation into the risk factors that are constant across populations and environments and those that are highly variable should be a central part of comparative investigations of early mortality.

Further, by refocusing on young children themselves — developing and interacting with their environments — we may construct a better "descriptive" statistic of the processes leading to survival or death and how these processes vary. As Harkness and Super note:

> Although the child and the environment are viewed as interactive systems, the household, as the center of early human life, is seen to be the focal mediator of this relationship, working largely through culturally constructed mechanisms. Because these can have different kinds of effects on children of different developmental status, we view the microenvironment *from the point of view of the child* in order to understand outcomes for child health and development (1994:218, emphasis added).

This perspective puts infants back into the picture when describing the roots of infant mortality. Documenting what infants

are doing should provide additional information about their risk of mortality. This does not imply that infants are somehow responsible for their ill-health or death, but rather that they should be included as participants in interactions that influence their well-being. This perspective further nests children within a developmental framework that begins at conception through intrauterine growth, birth, crawling, weaning, walking, and other points during a child's biological maturation and socialization, thus making infant mortality a component of the reproductive process.

CASE STUDY: EARLY MORTALITY AMONG THE TURKANA

Data to illustrate the utility of developmental stages in describing early mortality are derived from the Turkana, a nomadic pastoralist population of Kenya. The Turkana have been the focus of an ongoing multidisciplinary project since the early 1980s that has been concerned with ecology, demography, and health and disease, among other issues, in this pastoralist population. Unfortunately, there is no formal or ongoing census of the Turkana, in part due to their mobility and the fact that they are comprised of several interrelated subpopulations. Nor has there been an ongoing recording of births and deaths. And while the Turkana are numerate, they do not track chronological age. These constraints make demographic analysis of the Turkana very problematic.

To confront an initial demographic problem, the ages of the Turkana, a local event calendar was initiated in 1983 and its refinement and development is ongoing (Little and Leslie, 1990). The event calendar tries to pinpoint chronological years by reference to special characteristics of the wet and dry season, solar and lunar events, and epidemics, among other notable events. Two of the problems with the event calendar include the amount of time required to compile such a document and the fact that not all events for a given year are utilized by all Turkana groups. Further, although great care is taken to elicit information on season of birth by inquiring about early/late wet season or early/late dry season, it is quite common for the Turkana to remember wet or dry and no other distinguishing characteristics, leaving a 4–6 month margin of error. This makes it difficult to use the event calendar for aging infants and children. For her study of reproductive health, Pike (1996) found the calendar to be useful for determining the ages of women and the children of older women. The younger children of the women in the study were born in years that were not yet included in the event calendar, so further information needed to be added to the event calendar. Thus, as each researcher begins a field session the event calendar must be carefully updated and revised.

In recognition of the problem of accurate aging of children, Kenyan researchers affiliated with the Obstetrics and Gynecology branches of the Kenya Medical Research Institute (KEMRI) and the University of Nairobi began conducting surveys of child health using developmental stage information to enhance verbal autopsies. As part of a collaborative effort designed to extend the Kenyan survey on maternal and child health to the Turkana, similar questions were asked of the Turkana in Pike's investigation. Developmental stages recorded in the Turkana study were crawling, walking, or weaning status. During the interview process another category emerged, one that Turkana women defined as a "big child." The category "big child" identifies children who are old enough to herd small animals (approximately 6 years of age), up to early adolescence when children are able to herd larger animals. Although this category spans several years, it is a developmental category the Turkana consistently identified and is characterized by uniform behaviors.

During the collection of individual reproductive histories of Turkana women (n = 148) by Pike (1996), reported deaths of infants and children were investigated by reference to these stages (i.e., was this child weaned before it died, etc.). The event year and season during which a child was born and/or died was also recorded to estimate chronological age. The developmental stages of interest were terminated with the achievement of "big child" status; this closed the last developmental stage interval. It is important to note that this dataset includes only

TABLE 1. Distribution of early deaths by developmental stage

	Dead before stage	Attained stage before dying
Crawling	28% (8)	72% (20)
Walking	72% (20)	28% (8)
Weaning	44% (12)	56% (16)
"Big child"	100% (28)	0% (0)

dead children, as developmental stages were only recorded as part of verbal autopsies; analysis of the risk of death according to developmental stage is not possible with the data in their current form.

From the 148 reproductive histories, the total number of deaths reported for which there were complete developmental stage data was 28. Early deaths were considered to be those that occurred before the child reached "big child" status. Table 1 presents the distribution of deaths by each developmental stage (crawling, walking, weaning, and "big child") separately. It is evident that more deaths occurred after crawling (72%) than before this stage (28%), while if walking is considered, more deaths happened before the child was walking (72%) than after the child reached this stage (28%). If deaths are divided up by weaning status, over half (56%) of all deaths occurred after weaning.

The pattern of deaths is displayed in a temporal sequence in Figure 1, which further illustrates the interaction of the developmental stages of crawling, walking, and weaning. The developmental stages of crawling and walking occurred sequentially, while weaning took place across the array of motor developmental stages. As Figure 1 shows, 28% of the deaths occurred before crawling, 44% between the stages of crawling and walking, and 28% of deaths occurred after the child was walking. Two deaths occurred to children who were weaned before they crawled. Of those who crawled (n = 20), seven were weaned then died before walking, while an equal number walked and then were weaned and then died. Of the deaths to unweaned children, six occurred before crawling, five occurred after crawling but before walking, and only one occurred after walking.

Very early deaths (before crawling) were more common among unweaned children, obviously because most infants at this stage were not yet weaned. Between the stages of crawling and walking, when most deaths occurred, there were more deaths to weanlings than to infants who had not yet been weaned, suggesting the importance of weaning as a risk factor. After walking, the majority of deaths were to weaned children. At this stage the bias against weaned children may be due to weaning itself, or it may be related to more children in this developmental category having been weaned. There were no notable differences between males and females in the frequency of death at any given developmental stage, although the numbers of each sex in each category were so small as to preclude statistical comparison.

DISCUSSION

In their current form, the Turkana data can be used primarily to describe the developmental pattern of early deaths. As indicated above, developmental stage data were collected to supplement verbal autopsies, not specifically to test the approach advocated in this paper, and the sample of deaths was small. Nonetheless, this mode of describing deaths shows that early deaths, particularly neonatal deaths, were quite common (following a high rate of fetal death; if fetal deaths (n = 20) were included in the sample, they would represent 33% of all early deaths). Neither crawling nor walking appear to put infants at unique risk for mortality, but weaning after crawling does appear to be associated with a high frequency of death. This confirms previous studies showing the same effect; that is, weaning is the important risk factor for early death, independent of when it occurs.

These tentative results are in keeping with what is known about the cultural and ecological context of child survival among the Turkana. Turkana infants experience a wide array of stresses that begin at birth, fluctuate by season, and peak with the weaning process. From birth, they are exposed to numerous pathogens, less than sanitary conditions, and early dietary supplementation with animal butterfat (Gray, 1994, 1998). Mortality in the first few days of life is strongly associated with the intrauterine experience. Pike (1996) found that perinatal

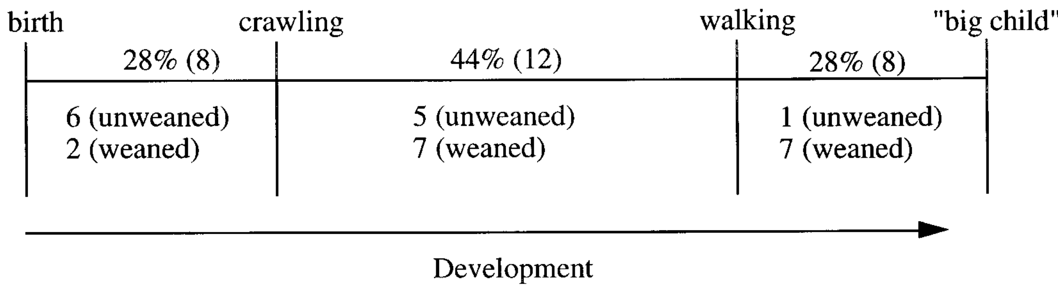

Fig. 1. Distribution of early deaths in Turkana across developmental stages.

mortality was linked to preterm delivery (assessed by the Dubowitz scoring system), small size and poor condition at birth, and to poor maternal health. In contrast, there is evidence to indicate that if Turkana infants survive the perinatal period, they are fairly well buffered until approximately 4–6 months of age, when growth faltering often occurs (Gray, 1999; Little et al., 1993; Pike, 1996). This increased vulnerability at 4–6 months is not associated with any clear changes in an infant's diet or caretaking, but may be evidenced by the substantial number of deaths occurring prior to crawling. Gray (1996, 1998, in press) has proposed that this age pattern of growth faltering may be linked to a combination of dry season food shortages, changes in nutrition, and subsequently compromised transition to the infant's active immunity. This shift in the immune system may be an important developmental transition for infants and needs to be examined further for its effects on mortality across populations.

The average age for weaning of Turkana children is approximately 21 months (Gray, 1994), and anecdotal observations indicate that women will wean if a baby is quite ill. With weaning, Turkana children show evidence of marked growth faltering, due in large part to the emotional stress and resulting anorexia of the weaning process (Gray, 1996). As a result, weaning appears to shift the balance in favor of mortality for Turkana infants and children who have already been exposed to numerous stresses.

The mortality risks associated with crawling and the more limited risks associated with walking also have some support in the Turkana literature. In general, Turkana children are permitted to crawl only rarely. Gray (1996) found that for the first 15–18 months Turkana children are in almost constant contact with their mothers, either being held or carried on the mother's back. However, if crawling children are also weaned, they are likely to be more independent of their mothers, leading to a higher risk of death. Thus, the combination of developmental stages is key to understanding mortality risk. When walking begins, children are much more likely to experience household accidents such as tripping over the cooking hearth and experiencing burns, but these accidents rarely result in mortality (Gray, 1992, 1998). Instead, infectious diseases such as acute respiratory illness, diarrhea (from contaminated water and drinking vessels), measles, and malaria were the most often cited reasons for morbidity-related deaths (Pike, 1996). Thus, the pattern of mortality after the first few weeks of life among the Turkana accentuates the relationship between caretaking, development, and environmental variables such as pathogen exposure, and suggests further questions for investigation.

CONCLUSION

This article has explored some of the problems associated with usage of the infant mortality rate and suggests an alternative method of collecting early mortality statistics that does not require accurate age accounting. We argue that the developmental stage approach outlined here has potential for overcoming problems with standard age-based mortality statistics, and may be useful to anthropologists doing field research, especially (though not exclusively) in small,

non-age numerate populations. Anthropological fieldwork is uniquely suited to the collection of more accurate information on early mortality and maturation than can be achieved in large-scale studies, and the goal of such data collection is often explicit cross-population or cross-environment comparisons. Human biologists already have contributed much to our understanding of the significance of variation in maturational ages across environments that could be incorporated into research on developmental stage and mortality (Beall, 1984).

The developmental pattern of risk of death is likely to reflect the underlying causes of death across populations and across environments. As such, it helps to distinguish between the genetic, ontogenetic, and environmental sources of mortality, and thereby may clarify the determinants of early death. At present, the Turkana data presented here provide only a tentative glimpse of the utility of the proposed developmental stage model of mortality. This approach needs to be tested more fully by a larger dataset that includes developmental information on both surviving and dead children.

ACKNOWLEDGMENTS

The assistance of Dr. Tsering Ladhol and others at the SNM hospital in Leh, Ladakh, is gratefully acknowledged for the study of Ladakhi newborns. The Ladakh study was funded by a grant from The Population Council and NSF grant #BNS-8912768. For the Turkana study, advice offered by Dr. Leah A. Kirumbi, of the Kenya Medical Research Institute, and Dr. Christine S. Kigondu, of the University of Nairobi is gratefully acknowledged. Their collaborative efforts to understand maternal and child health in Kenya are noteworthy. This study is published with the approval of the Director of KEMRI. The Turkana district officers and the district commissioner, the Hon. S.M. Toyya, are acknowledged for their cooperation. Financial support for the Turkana was provided by a dissertation fellowship from the Population Council, Wenner-Gren Foundation, and NSF grants BNS-8718477, and DBS-9207837. The first author thanks E.A. Hammel and others at the Dept. of Demography at UC Berkeley for their comments on earlier drafts of the manuscript. The comments of two anonymous reviewers were very helpful.

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